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DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
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MINING METHODS AND COSTS AT THE CHAMPION COPPER MINE, PAINESDALE, MICH.

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MINING METHODS AND COSTS AT THE CHAMPION COPPER MINE, PAINESDALE, MICH.[1]

By Albert Mendelsohn[2]

INTRODUCTION

This paper, describing the mining practice at the Champion mine of the Copper Range Copper Mining Co., is one of a series of papers on mining methods and costs being prepared by the United States Bureau of Mines.

Mining practice at the Champion mine has undergone considerable change during the last four years. Previous to that time the mine was worked by the horizontal cut-and-fill method, the stopes starting near the shafts and advancing away from them (fig. 2). The floor pillars were mined by the inclined cut-and-fill method, working on the retreat or toward the shafts (fig. 1). At present the mine is being developed to stope entirely on the retreat by a sublevel inclined cut-and-fill method.

ACKNOWLEDGMENT

The author is indebted to the Champion mine organization for much of the detailed information given in this paper.

HISTORY

The Baltic lode was discovered on what is now the Champion property by Dr. L. L. Hubbard in May, 1899. The Champion Copper Co. was incorporated in December, 1899, for the purpose of exploiting the Baltic lode on the Champion property. During 1899, 1900, and 1901. developing and prospecting were done, and in 1902 the first ore was shipped. It was not until about 1909 that the mine reached what might be considered a "balanced" condition, with shaft sinking, drifting, and ore reserves developed well ahead of production.

GEOLOGY

A recent and very thorough survey of the geology of the district and of this mine is contained in Professional Paper 144, The Copper Deposits of Michigan, by B. S. Butler and W. S. Burbank, published by the United States Geological Survey in 1929. The following brief remarks on the geology of the Champion mine are made only to give the reader a summary of the physical conditions in the mine which have affected the mining practice.

At the Champion mine the copper is found in the upper bubble-studded, brecciated capping of a lava flow about 190 feet thick. Almost all the mines in the district find their copper in the top of similar flows. These flows have been tilted so that they dip at angles of 30 to 70°. As a rule, the lodes are unusually straight for very long distances on the strike. The hanging wall of a lode is the bottom of the next succeeding lava flow. The footwall of a lode is the trap lying under the amygduloidal, bubble-studded top of the flow. In some places the lodes outcrop; in other places they are covered with heavy glacial drift.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6515."

[2] One of the consulting engineers, U. S. Bureau of Mines, and general superintendent, The Copper Range Co.

BALTIC LODE

The lode being mined at the Champion mine is the heavily brecciated top of what is known in the district as the Baltic flow. The brecciated portion of the lode ranges from 6 to 50 feet in width. Under this breccia is the thinner, tighter, amygduloidal portion of the lode; under the amygduloidal portion is the trap. Native copper is found deposited in the rock fragments of the breccia, in the cementing material of the breccia, in the amygdules, and in the trappy rock under the amygduloidal part of the lode; in some places masses of copper many tons in weight extend far into the foot trap of the lode.

The Baltic lode on Champion property is 8,000 feet in length, is very straight along the strike, and dips uniformly at 70° to the west for 3,000 feet in depth, at which point the dip begins to flatten slightly. The width of the copper-bearing portion of the lode ranges from 10 feet to as much as 80 feet in a few places. The average width now mined is 17 feet.

The lode rock is hard; the standard 1-man drilling machines used in the mine drill 10 inches to 14 inches a minute, unless mass copper is encountered. The hanging wall, which is the bottom of another flow and is of a blocky structure due to quick cooling, is full of minute seams running in apparently every direction, with larger seams running parallel to the strike and dip. When exposed over an area of only a few square yards and unsupported by timber or fill the hanging wall will begin to disintegrate and fall into the stope. There is no definite foot slip; the lode becomes more and more trappy on the foot side the deeper it is followed into the flow. The wide portions of the lode seem to be due to large accumulations of fragmental material on the very top of the flow. In some places the lode is split into two branches separated by very trappy, amygduloidal rock.

Copper is not distributed uniformly in the lode. In a large way it follows chutes pitching from the north down toward the south. The copper may occur on the hanging side, in the middle, or on the foot side of the lode, or it may be distributed from hanging to foot. In a smaller way copper occurs in patches surrounded by barren lode rock. It is very patchy along the strike of the lode and across the lode, so that the absence of copper in any drift opening in one of the chutes may mean only that the copper lies to the foot or hanging of the opening, or that it may lie just ahead of the opening.

There are many cross slips or seams running parallel to the strike but dipping at nearly 90°. Even the larger cross slips do not throw the lode more than a few feet. The southern boundary of the Champion Mine is a fractured zone of considerable extent.

The rock shipped from the Champion mine for the last five months of 1930 ran 46 pounds of refined copper per ton. Before hand-sorting the rock broken in stopes and drifts ran 25 pounds per ton. It is estimated that before selection of stoping ground all the lode rock opened by development would have produced only 9 pounds per ton.

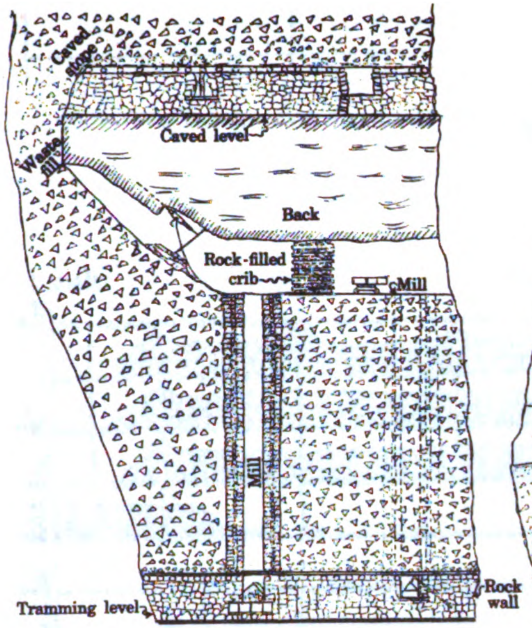
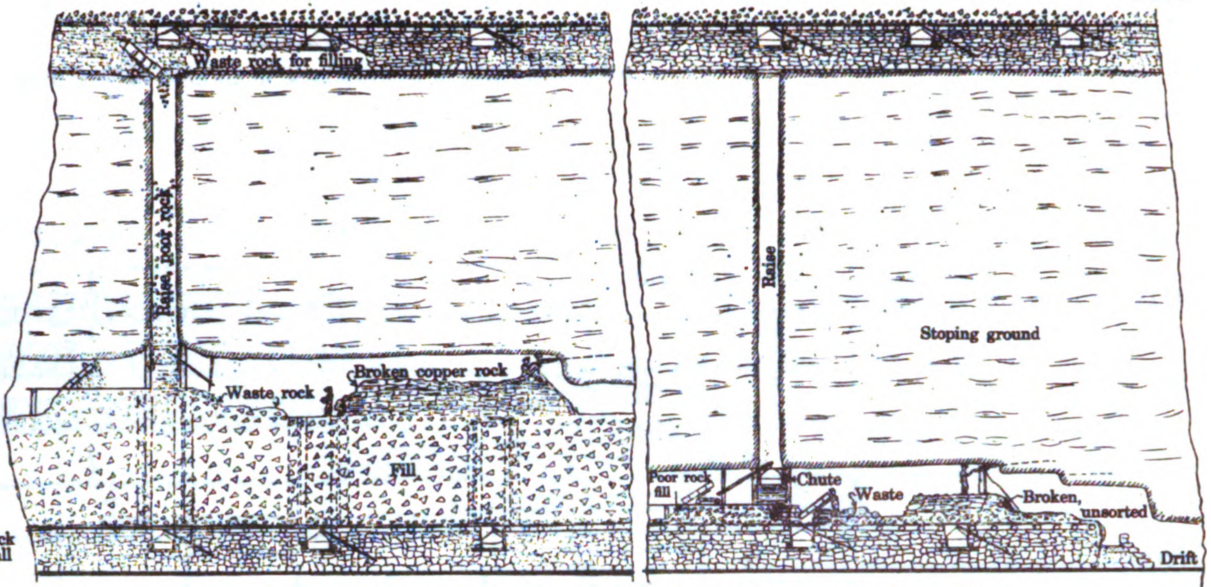


Figure 1.–Method of extracting floor pillar, old stoping system



STOPE IN REGULAR OPERATION

STARTING STOPE

Figure 2.–Old stoping system

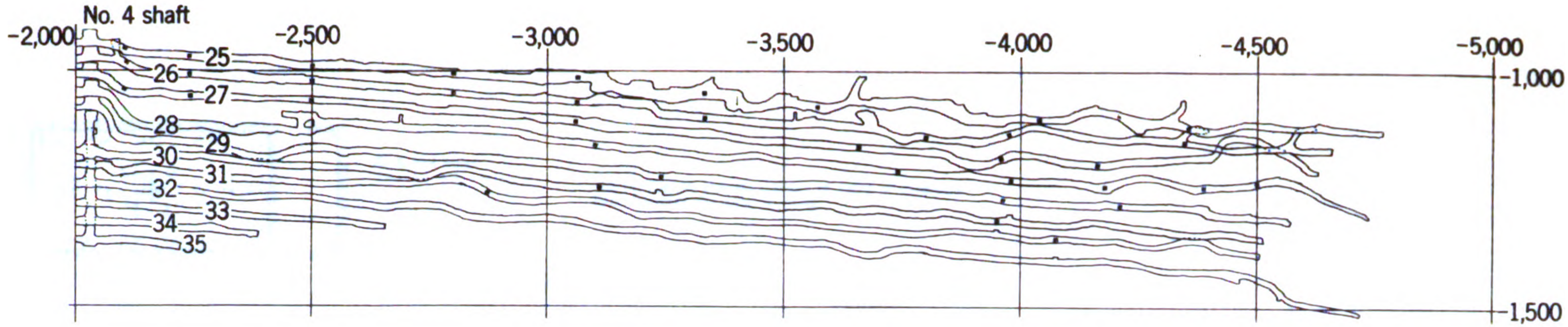


Figure 3.-Plan of drifts at southern end of Champion mine

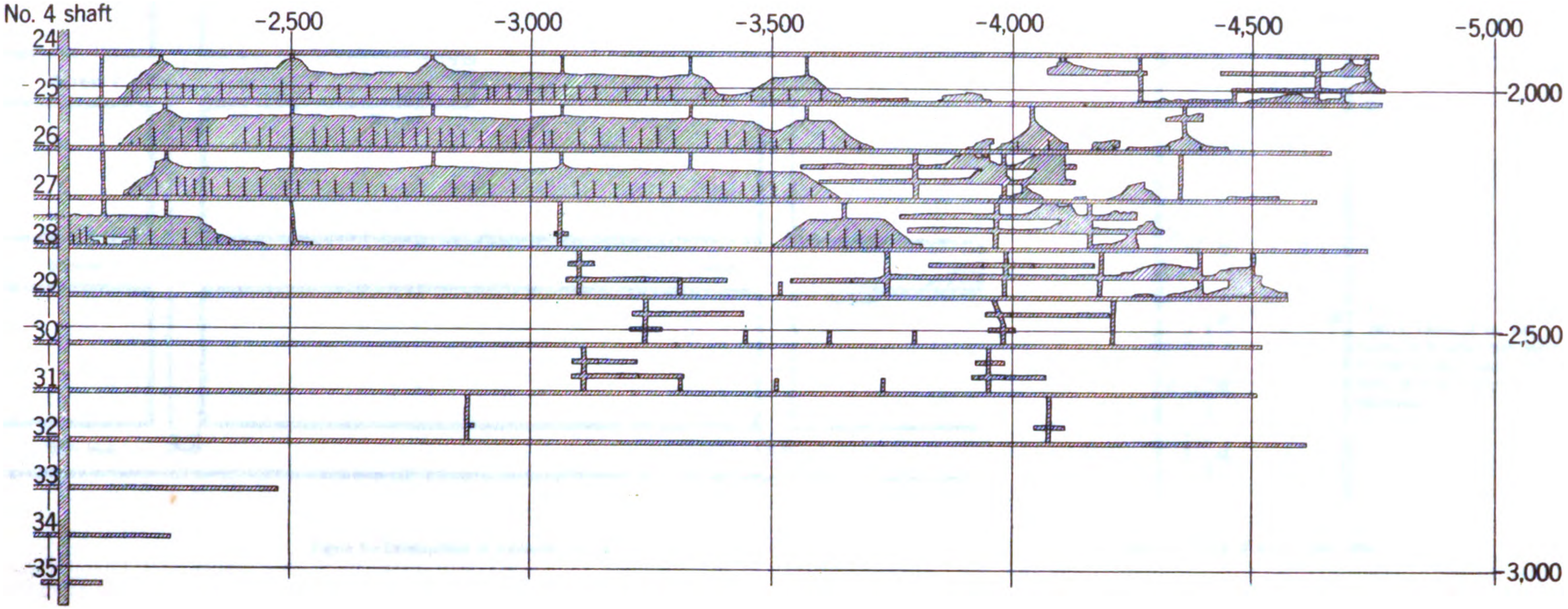
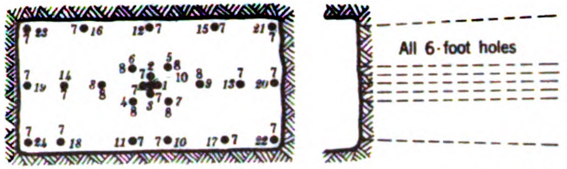


Figure 4.-Stoped areas at southern end of Champion mine



NOTE: Figures indicate number of sticks of dynamite:
Italic numbers the order of firing

Figure 5a.—Drill round

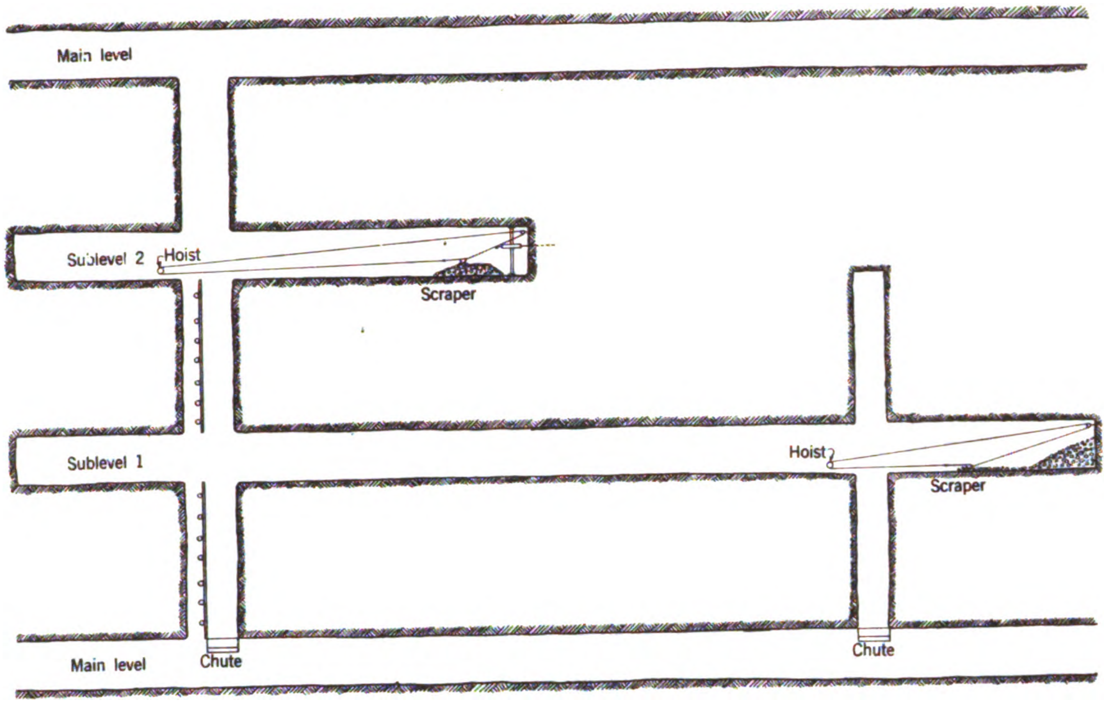
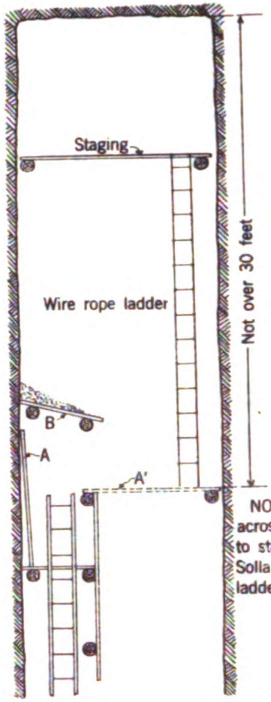


Figure 5.—Development of sublevels and raises



NOTE: Planks A are laid across at A' when men ascend to start a new round. Sollar B is to protect main ladderway

Figure 5b.—Top of 4 by 8 foot raise

METHODS OF PROSPECTING AND EXPLORATION

Where the glacial drift is not too heavy prospecting is generally done by test pitting. A large amount of diamond-drill exploration has been done in the district. Within the mines exploration is done by crosscuts and drifts and by diamond drilling. Geophysical prospecting methods have been successfully used to follow the major geological formations in districts covered by heavy glacial drift.

METHODS OF SAMPLING AND ESTIMATE OF TONNAGES AND VALUES

At none of the mines operating in the copper country of Michigan is sampling done. It has been attempted in a few places but proved too costly, and the results were not dependable.

Tonnages and values are estimated by the mining captains or engineers, or both, who designate the monthly openings as "good", "fair", or "poor". The decision as to what ground can be mined profitably is made by the superintendent and mining captains, who rely on their experience in judging the ground.

METHODS OF DEVELOPMENT AND MINING

The Champion mine is developed by four inclined shafts, three of which are in operation at present. The shafts were started on the lode on a dip of about 70°. Thus far this dip angle has been satisfactory, but at present depths the lode is beginning to flatten. Main levels are driven from the shafts at intervals of 100 feet on the dip. These main levels are driven a convenient width (from 9 feet to 13 feet), depending on the character of the ground with respect to copper and "loose" ground. These main levels follow the copper in so far as is possible but avoid sharp curves such as would make for inefficient haulage. With a lode as wide as the Baltic, and the copper occurring as it does on either the foot side or hanging, or both, supervision of these main levels drifts becomes very important. These drifts explore as well as develop. In former years, before the ground was under stress these main-level drifts were driven with speed as the second consideration, the chief concern being to develop the copper-bearing portion of the lode to its full width as the drift advanced. Such a scheme gave assurance that the level, when finally walled or timbered, would be under the copper, and stoping could proceed in an orderly manner without further exploration. With the decision to mine "on the retreat" the main-level drifts were given a minimum width for the sake of reducing maintenance costs and increasing speed of advance, but at the same time they are closely watched and allowed to meander in an effort to keep in the best part of the lode and thus pay their way as driven. Figure 3 shows a plan of the drifts in the southern end of the Champion mine.

Figure 4 shows stoped areas on the higher levels and development for sublevel mining on the bottom levels, and Figure 5 shows a section and details of the mine developed for sublevel mining on the retreat. Raises are approximately 200 feet apart. Subdrifts are driven 33 and 67 feet, respectively, above the main level rails. Subdrifts are driven the full width of the copper-bearing portion of the lode. Speed of drifting is not the first consideration, the chief concern here being to develop and explore thoroughly, so that when stoping starts there need be only a minimum of delay for further exploration.

Shafts

All shafts at the Champion mine are 9 feet by 23 feet. rock measurement, and are sunk on a dip of 70°. The shafts are in trap rock, which is very hard but full of slips and fractures which necessitate complete timbering. Timber consists of dividers, wall plates, sleepers, spare pieces, and studdles of 12 by 12 inch Douglass fir, stringers of 8 by 10 inch fir, and lagging of round, peeled, cedar poles. Sixty-pound rails are used in the shafts.

Skips

The skips have a capacity of 6 tons and have side plates extending up well under the bail, to prevent spillage into the shaft when they are loaded. Figure 6 shows a safety bonnet for the skip, and Figure 7 shows the plat and loading arrangement with the skip in loading position. The dumping arrangement for skips is shown in Figure 8.

Cages

Cages (fig. 9) have two or three decks, holding 12 men on a deck. The upper and middle deck floors and the top of the cage are removable, enabling the cage to be converted quickly into a timber and supply truck.

Shaft Sinking

A shaft-sinking crew consists of four men and one puffer boy on each of the two shifts. These four men drill, blast, muck, and timber. The timber is kept down within 12 feet of where the men are working. Shaft lines are set by the engineers and the head mine timberman.

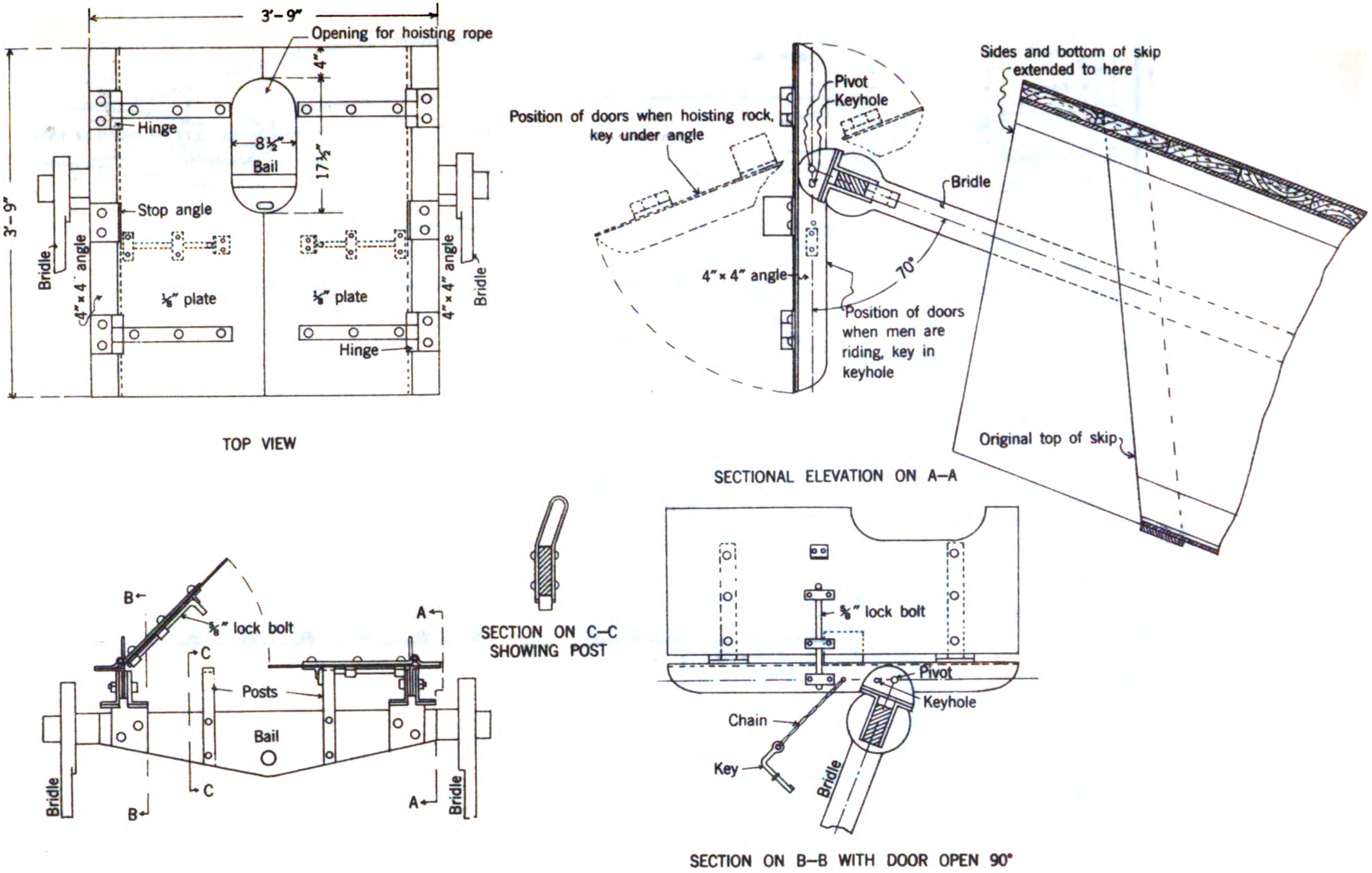
Figure 10a shows the drill round used at present in shaft sinking. Machines are Gardner-Denver No. 11 sinkers and are used with water.

Fractured ground frequently causes the holes to cave in, and for this reason light machines which can be easily raised or lowered by the miners while drilling are used.

Seven-eighths-inch hexagon, hollow drill steel, collared, with 3¼-inch shank, is used. Double Carr cross bits are used, with gages as follows: Starter, 1-7/16 inches; 4 foot, 1-3/8 inches; 6 foot, 1-5/16 inches; 8 foot, 1¼ inches. Drill steel is handled in and out of the mine in bundles. Blasting is done with fuse and cap, using 1-inch Giant Gelatine, 40 per cent powder.

Mucking is being done at present by hand into 1000-pound capacity buckets; see Figure 10b, which shows the shaft-sinking method. These buckets are dumped automatically into a flop pan controlled by the puffer boy, the rock running into a bin of 30 tons capacity. Loading from the bin into the skip is done by means of a sliding chute. The bucket carriage runs on an 8-inch I beam.

Present practice is to sink 300 feet before letting out the main hoisting ropes to bring the skip down. A rock pentice 8 feet thick, is left under the skip pit to protect the men engaged in sinking operations. When 300 feet of sinking has been completed stringers are put in and the level stations cut. Then the pentice is blasted out, and the skip roads are connected.



TOP VIEW

SECTIONAL ELEVATION ON A–A

SECTION ON C–C SHOWING POST

SECTION ON B–B WITH DOOR OPEN 90°

Figure 6.–Safety bonnet for skip

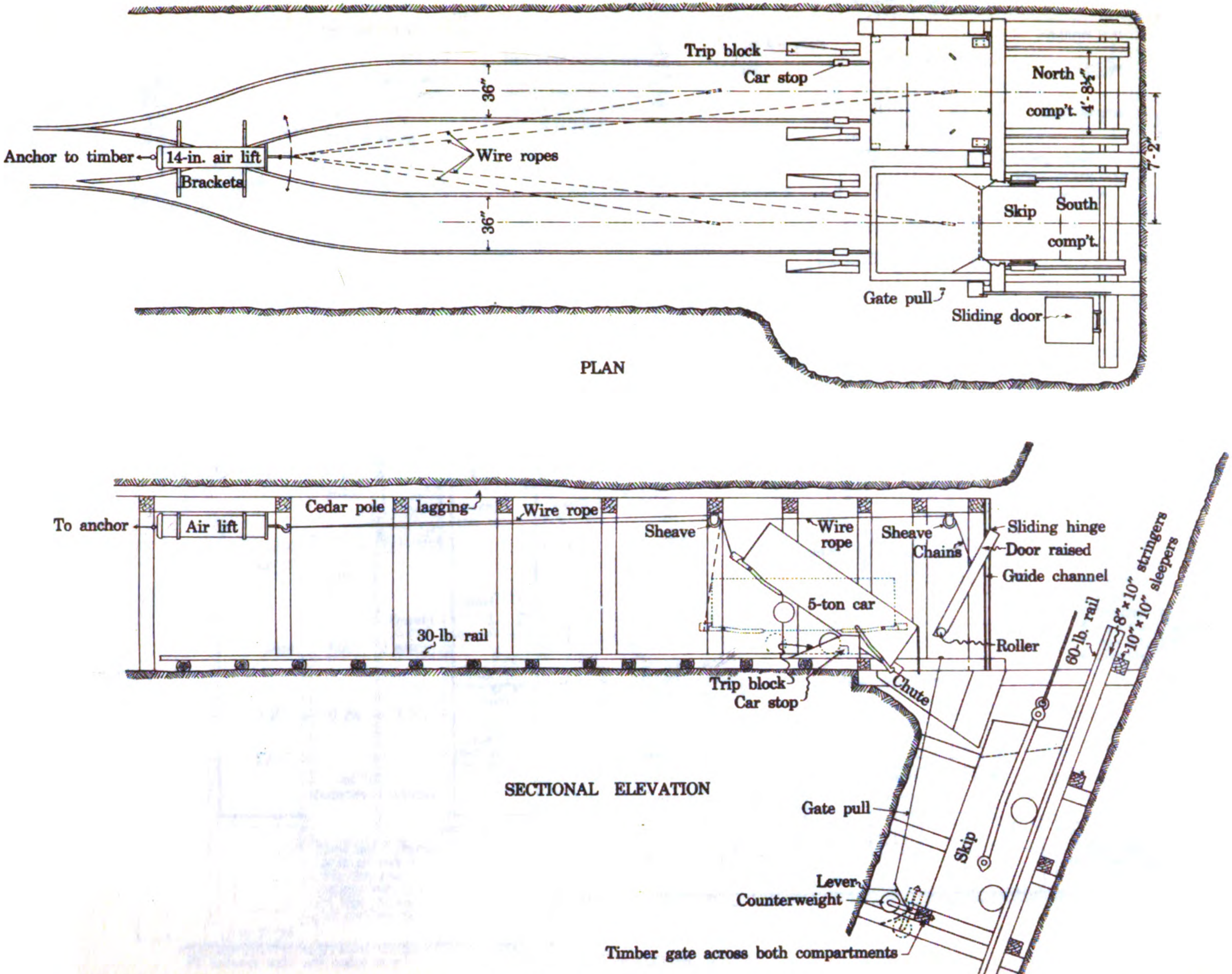


Figure 7.—Plat and loading arrangement

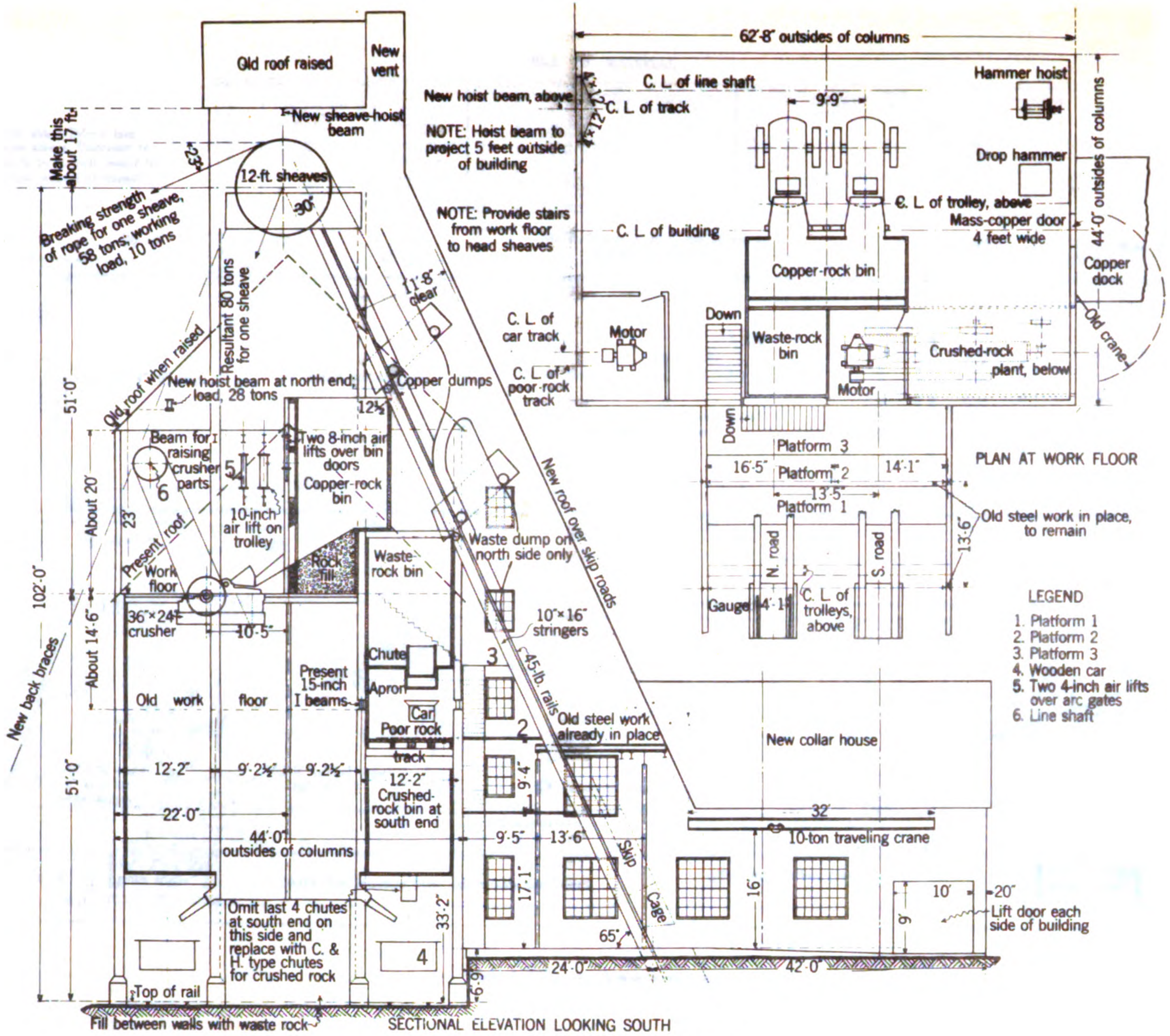


Figure 8.–Skip-dumping arrangement in rock house

BILL OF MATERIAL

Mark	Required	Size	Length	
1	2	9"L 20 lb/ft.	21'0"	Sill
11	2	4"L 7.25 lb/ft.	21'0"	Top stringer
2	2	4×4×1/2"L	21'0"	Bottom angle
3	2	4×4×3/8"L	3'7"	Upper end angle
4	1	do.	3'2"	Do.
5	2	do.	4'3"	Lower end angle
6	1	do.	3'2"	Do.
7	2	do.	3'7"	Deck support
8	2	do.	3'7"	Do.
9	2	3×3×1/4"L	3'2"	Removable deck
A	2	do.	4'8"	Brace
B	2	do.	7'8"	Do.
C	2	do.	8'0"	Do.
10	2	1/2"×52 1/2"Pl	10'4"	Bottom plate
12	2	5/8"mesh, 42"	18'6"	Side screening
13	2	1/2"×16" Pl.	4'0"	Side plates
14	2	1/2"×10" Pl.	4'6"	Side plates, lower
15	2	1/2"×48" Pl.	4'10"	Side plates, upper
16	2	1/4"×10 1/2"Pl	1'5"	Gusset
17	2	1/4"×10" Pl.	1'3"	Do.
18	2	1/4"×12" Pl.	1'8"	Do.
19	2	do.	1'8"	Do.
20	1	1/2"×[illegible]" Pl.	4'0"	Cover plate
21	1	1/2"×22" Pl.	4'0"	Cover door
22	2	1/2"×10" Pl.	0'10"	Reinforcing plate
23	2	1/2"×10" Pl.	4'0"	
24	2	1/2"×43" Pl.	3'10"	Deck floor
25	2	3/8"×10" Pl.	3'7"	Deck front
26	4			Standard hub
27	4			Standard wheel
28	4			Standard shoe
29	4			Standard guide
30	1			Standard bail
31	2			Standard bridle and draft lug
32	1	1/2"×47" Pl.	4'3"	Lower end plate

NOTE: Wire netting for sides; Tyler's best double crimped iron-wire screen: Diameter of wire 0.1620 inch, mesh ⅝ by ⅝ inch center to center of wires, 42 inches wide: Galvanized after weaving

NOTE: Braces A, B, C, not shown on this side of drawing

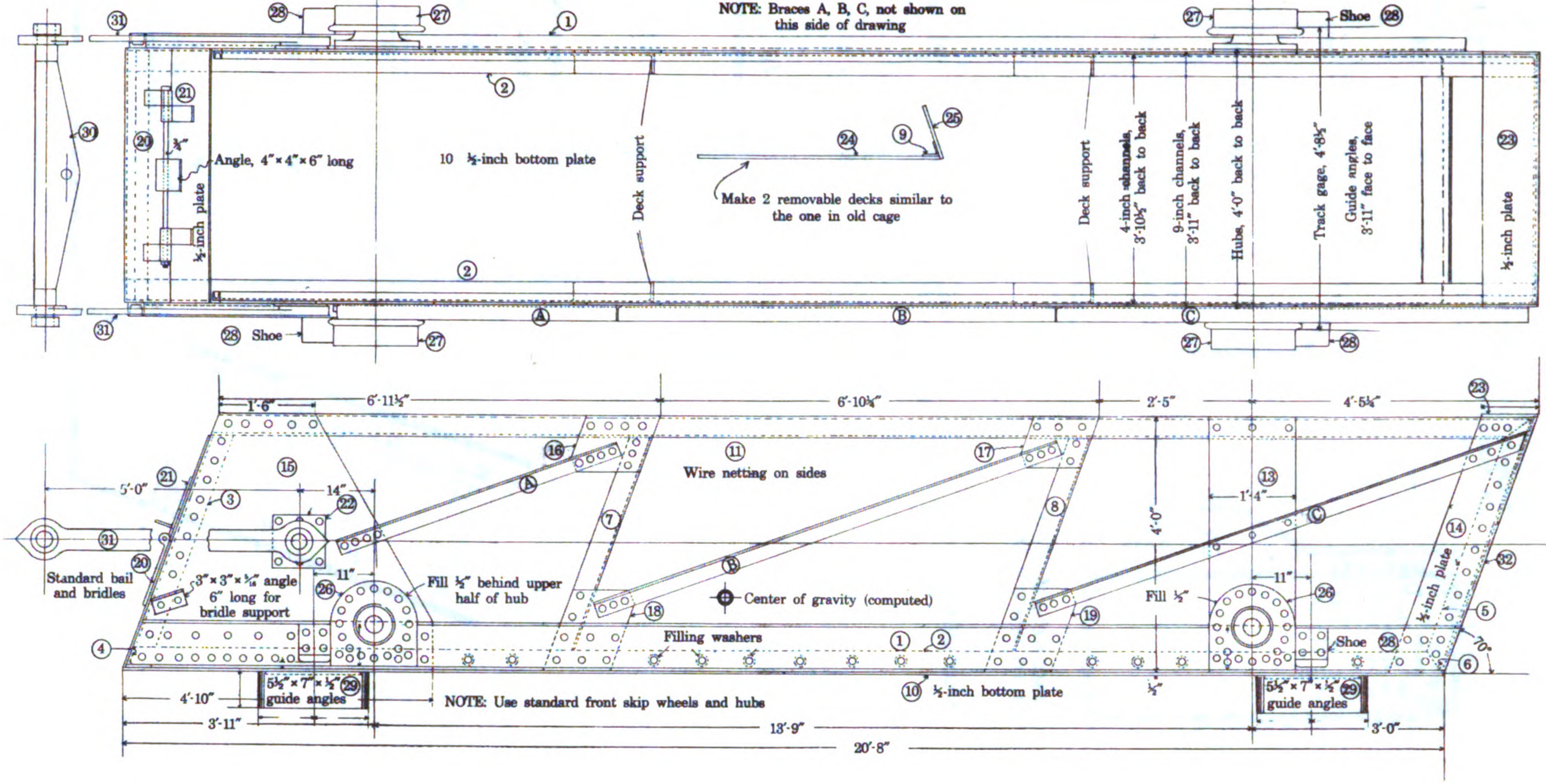
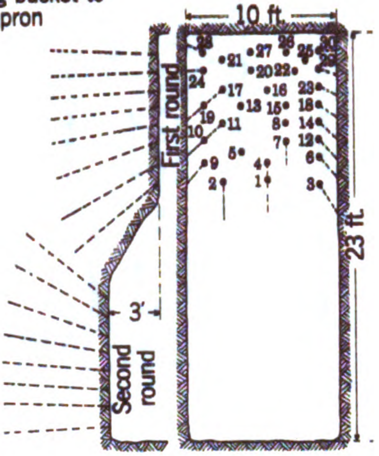


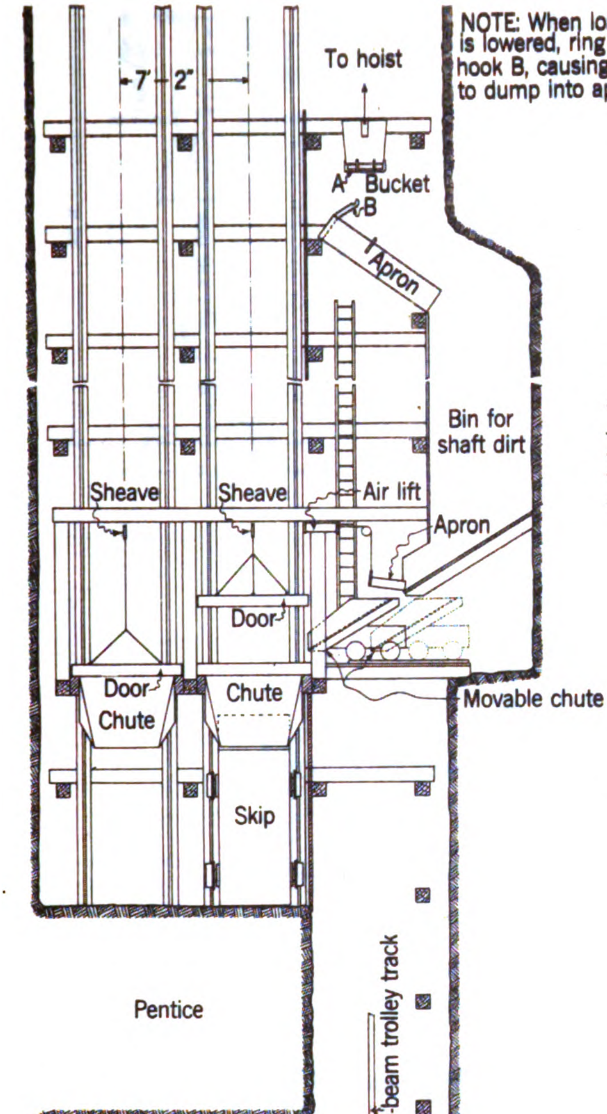
Figure 9.—Design for three-deck man car



NOTE: All 6-foot holes, 6 sticks of powder per hole

Figure 10a.-Drill round

NOTE: When loaded bucket is lowered, ring A engages hook B, causing bucket to to dump into apron



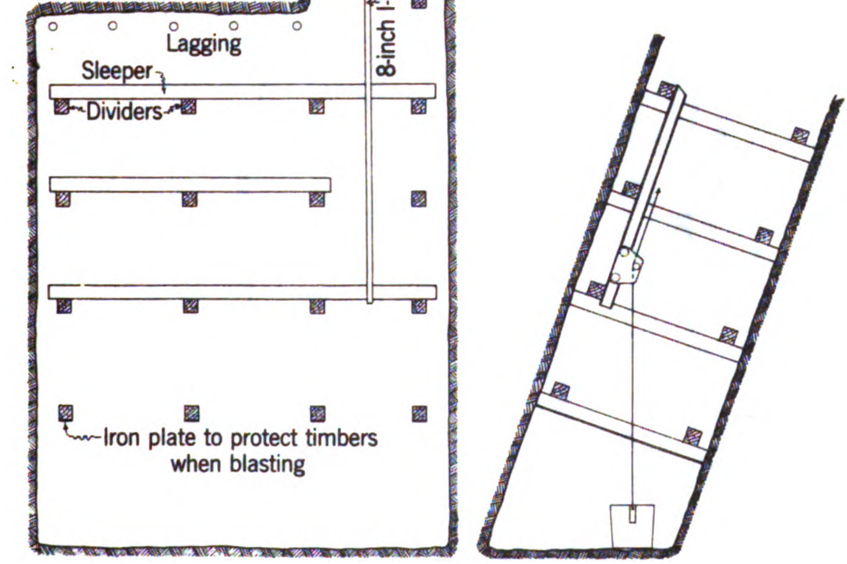
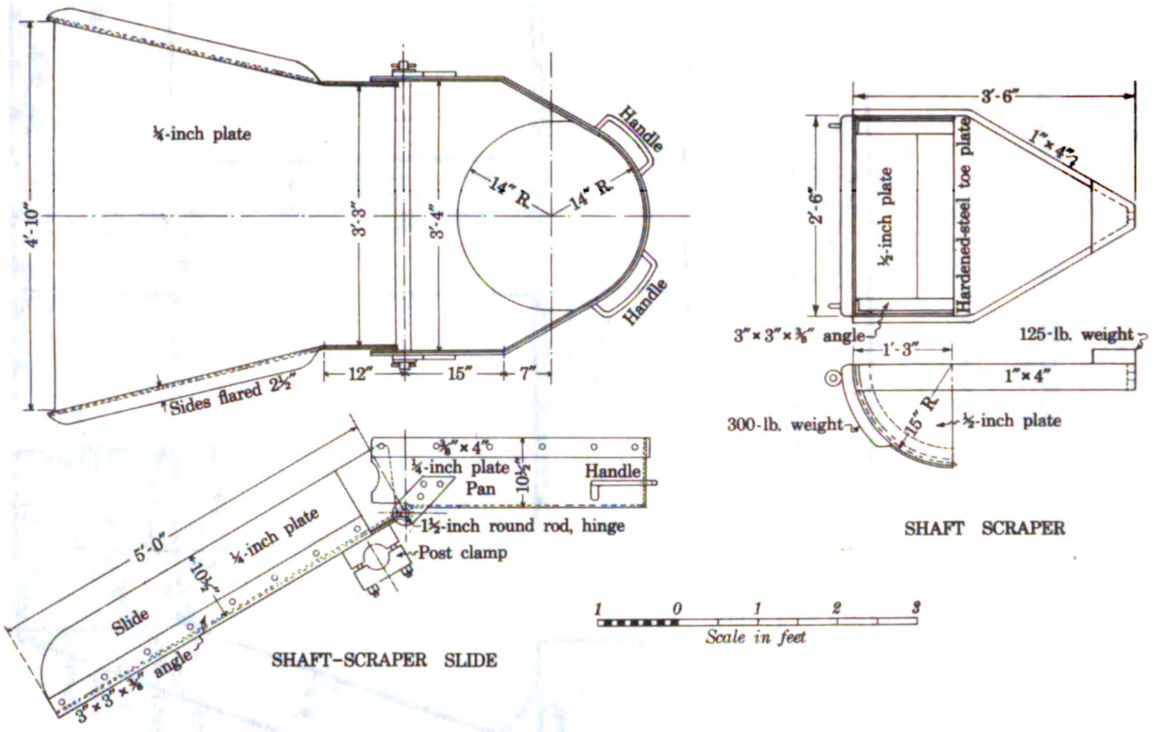

Pentice
8-inch I-beam trolley track
Lagging
Sleeper
Dividers
Iron plate to protect timbers when blasting

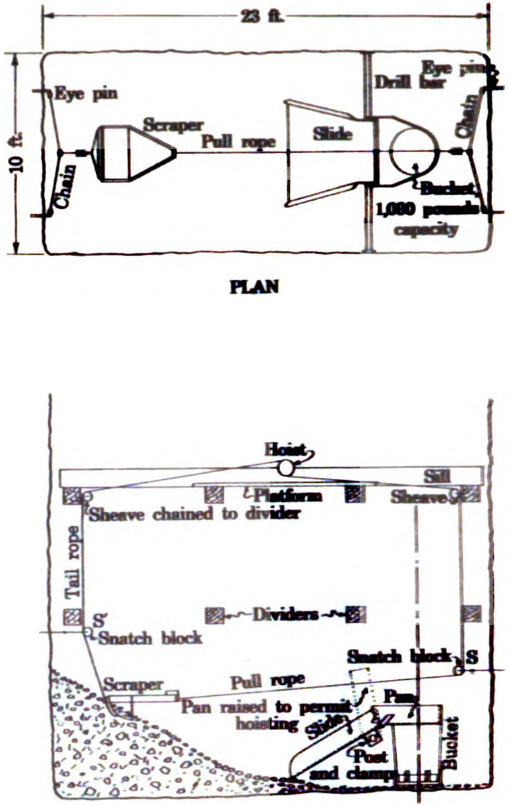
Figure 10b.-Shaft-sinking method



SHAFT-SCRAPER SLIDE

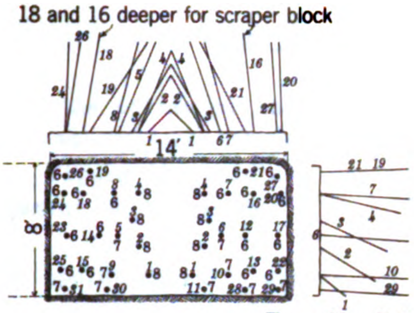
SHAFT SCRAPER

Figure 11.–Design of scraper and slide for mucking in shaft



PLAN

Figure 12.–Scraper mucking at bottom of shaft;
general arrangement



NOTE: Figures indicate number of sticks of dynamite: Italic figures the order of firing

Figure 13a.-Drill round

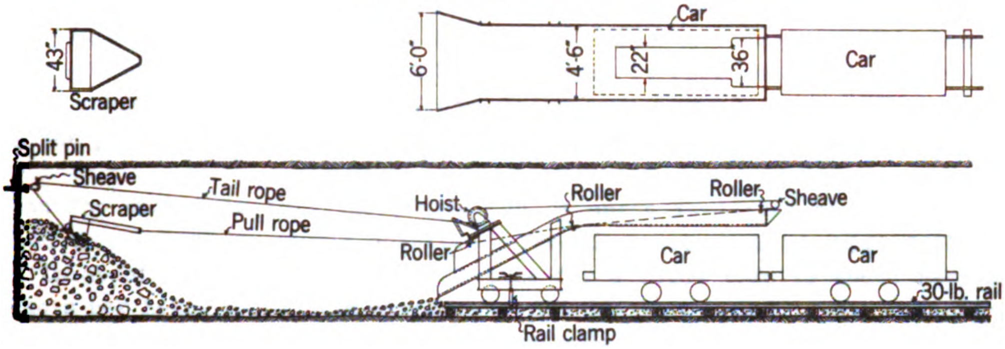


Figure 13.-Drift-mucking method

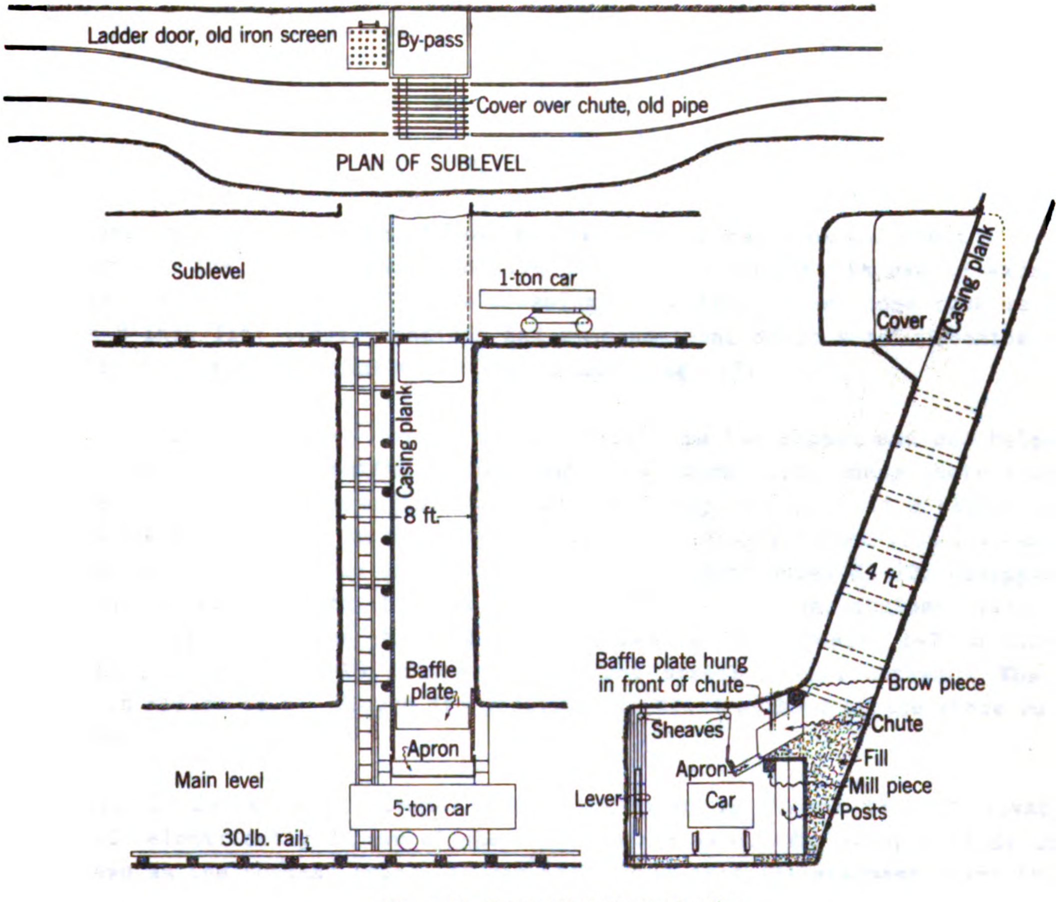


Figure 14.-Raise and chute construction

Shaft Mucking With Scraper

Mucking in the bottom of the shaft by means of a scraper and slide is now being tried. It is yet in an experimental stage, having been used only a few days, but is showing promising results. Figure 11 gives the designs of scraper and slide, and Figure 12 shows the general arrangement in the shaft.

The first operation is to scrape all or most of the dirt to the north end of the shaft; then the slide is set up as low as possible, and the scraper is reversed for loading the bucket. When the south cut is being blasted most of the dirt is thrown north, which reduces the preliminary scraping work. The slide is attached by clamps to a horizontal bar or post. Sheaves (or snatch blocks) S and S' are attached by clevices to chains strung across the ends of the shaft through eye pins. These chains have several rings or links, which permit changing the position of the outfit toward foot or hanging as desired.

When the bucket is full the hinged pan or apron is turned back, and the scraper rope is pulled to one side to permit hoisting. Two good scraper loads will fill the 1,000-pound bucket in about 20 seconds. The total time for a round trip is about 2½ minutes, or about 25 buckets per hour, hoisting a distance of 150 feet. A larger bucket is contemplated. When the mucking is finished slide and scraper are hoisted up and hung out of the way until needed again.

The scraper hoist is mounted on a platform far enough above the bottom to be safe from blasting. Of course, some hand mucking will still have to be done, when sinking through the pentice, before the shaft is widened. As stated above, the scheme is new, and some difficulties will no doubt develop that will have to be ironed out, but in the main it is working very well.

Drifts

Main-level drifts are driven 13 feet wide when in copper rock and about 9 feet wide when in barren rock. The rock is hard and firm, and little support is needed except for loose material in the neighborhood of slips crossing the drift. This loose rock is caught up by props with 8-inch flat timber headings and by occasional drift sets. Mucking in the main level drifts is done with portable scraper slides (fig. 13).

The standard organization for main-level drifts is two miners and one helper per shift on each of the two 8-hour shifts. These men mine, muck, tram, dump their rock into the skip, take care of the slusher engine and slide, and keep the drift in a clean, orderly condition. There are two machines in each drift, rigged on ordinary 3-inch iron-pipe columns, single jack, with 3-inch arms. The machines are Ingersoll-Rand Model RA-72, equipped with tappet chuck, using water. The drill steel is 1-inch hollow hexagon, lugless, with Double Carr cross bits. The gages of the bits are as follows: 2 foot steels, 1-7/16 inches; 4 foot, 1-3/8 inches; 6-foot, 1-5/16 inches; and 8-foot steels, 1-1/4 inches. The round drilled is shown in Figure 13-a. Miners are permitted to blast as soon as the whole round of holes is completed.

The dirt is mucked with scraper slide, as shown in Figure 13. Sullivan Type HDE-4, 15 hp., D.C. electrically driven slusher engines are used. The scraper slide used is that commonly known as the "Osana" type. It has been found that the sharpest curve that can be driven with this type scraper slide in a drift 10 feet wide is of 35-foot radius. It requires an average of two hours to muck out a round.

Raises

Raises are driven 4 feet by 8 feet, rock measurement. The rock is hard and firm, and little support is needed. However, inasmuch as the raises are to be used later for ladder road and ore pass they are timbered when driven, as shown in Figure 14. The raises are always put up at a point where there is a good showing of copper, and consequently usually pay their way.

Machines used are self-rotating and self-feeding wet stopers. Two miners working together with two machines comprise the raising crew and work only one shift a day. Drills used are 1-inch hollow hexagon. The starter bit is 1-9/16 inches, the second steel 1-1/2 inches, and the third steel 1-7/16 inches. The round drilled is shown in Figure 5a.

When the raise is advanced 30 feet from the level it is timbered as shown in Figure 14, and a chute for handling the muck is built at the bottom. The set of timbers at the top of the ladder road is covered with heavy timber to protect the ladder road when blasting is done. Lagging is omitted from the top set, between the ladder road and the dirt compartment, to allow for ventilation. When the raise is advanced 30 feet above the timber it is again timbered and lagged, as shown in Figures 14 and 5b.

MINING (STOPING)

The method of mining at the Champion mine is being changed from horizontal cut-and-fill working on the advance to sublevel inclined cut-and-fill, working on the retreat.

Old Mining Method

The Baltic mining method, which is well described in Peele's Handbook, is still being used in the upper levels of the Champion mine. Drifts were driven 8 feet high and the full width of the copper bearing part of the lode. When 200 to 500 feet had been drifted in copper ground the drift was enlarged to a height of 14 feet. Dry walls of discarded rock were built on the foot and hanging sides to a height of 7 feet and the top covered with timber and lagging (fig. 15 which is a section through a level, old mining method). Raises were put up from the top of this wall at intervals of about 500 feet, and fill was dropped from the level above and spread behind the foot and hanging dry walls. In the footwall mills (ore passes) were laid out at intervals of 33 feet. Horizontal cuts about 4½ feet thick, were taken off the back. This rock was picked, the copper rock was trammed to the mills in small stope cars, and the rock discarded was thrown to the foot and hanging sides of the stopes. The mills (ore chutes) were then walled up with the discarded rock, and the stope was again filled with waste rock dumped down the raise from the level above. When stoping had begun on the top of the dry walls the drift was again driven until enough ground had been opened for another stope.

Horizontal cut-and-fill stoping continued for the entire length of the level until all but 30 feet under the level above had been mined out. The extraction of this 30-foot floor pillar was made by inclined cut-and-fill stoping, commencing at the inside boundary (figures 1, 2 and 16). Filling for the inclined cut and fill was obtained by wrecking the level above, the last round blasted allowing the fill from above to rush down into the stope.

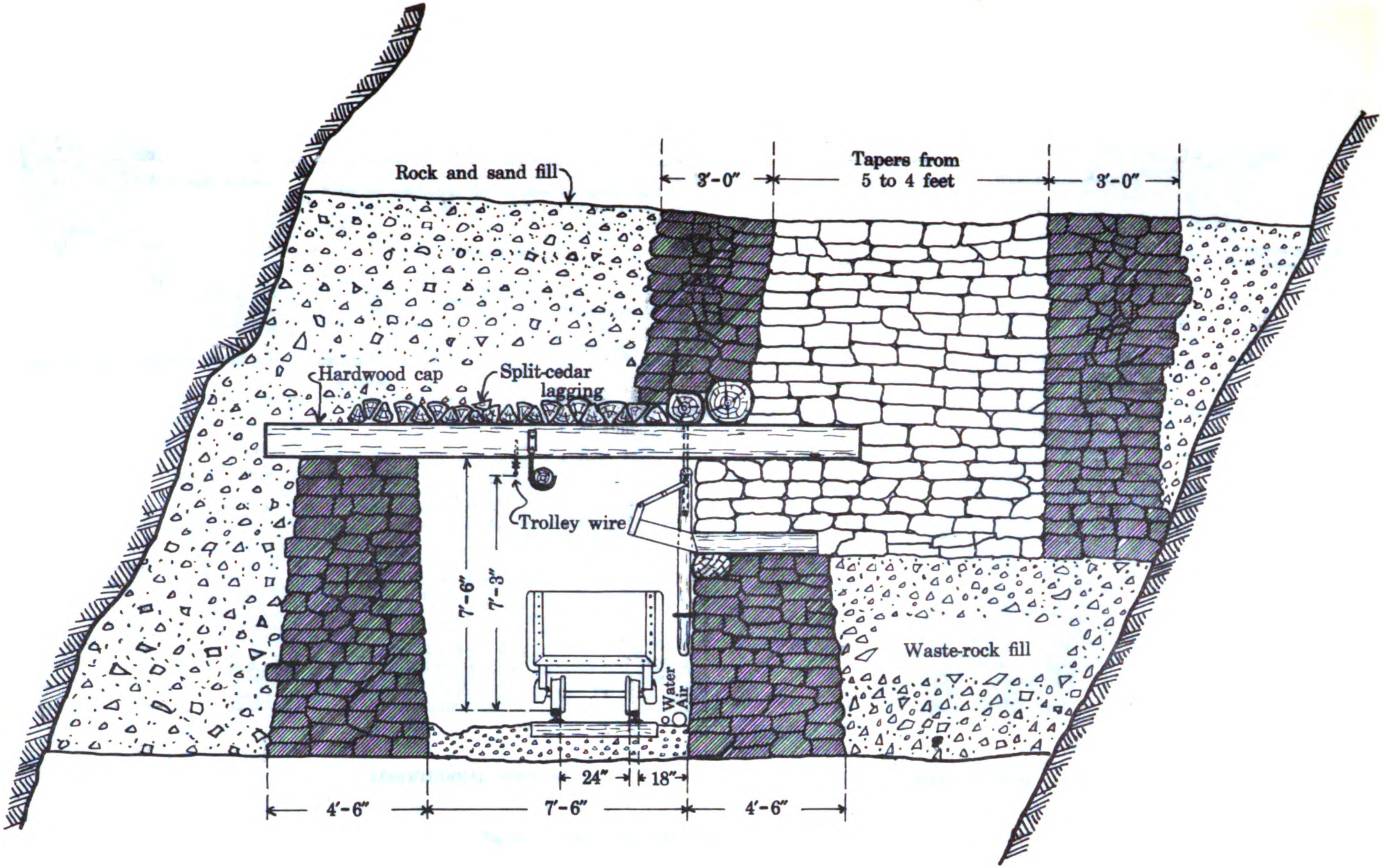
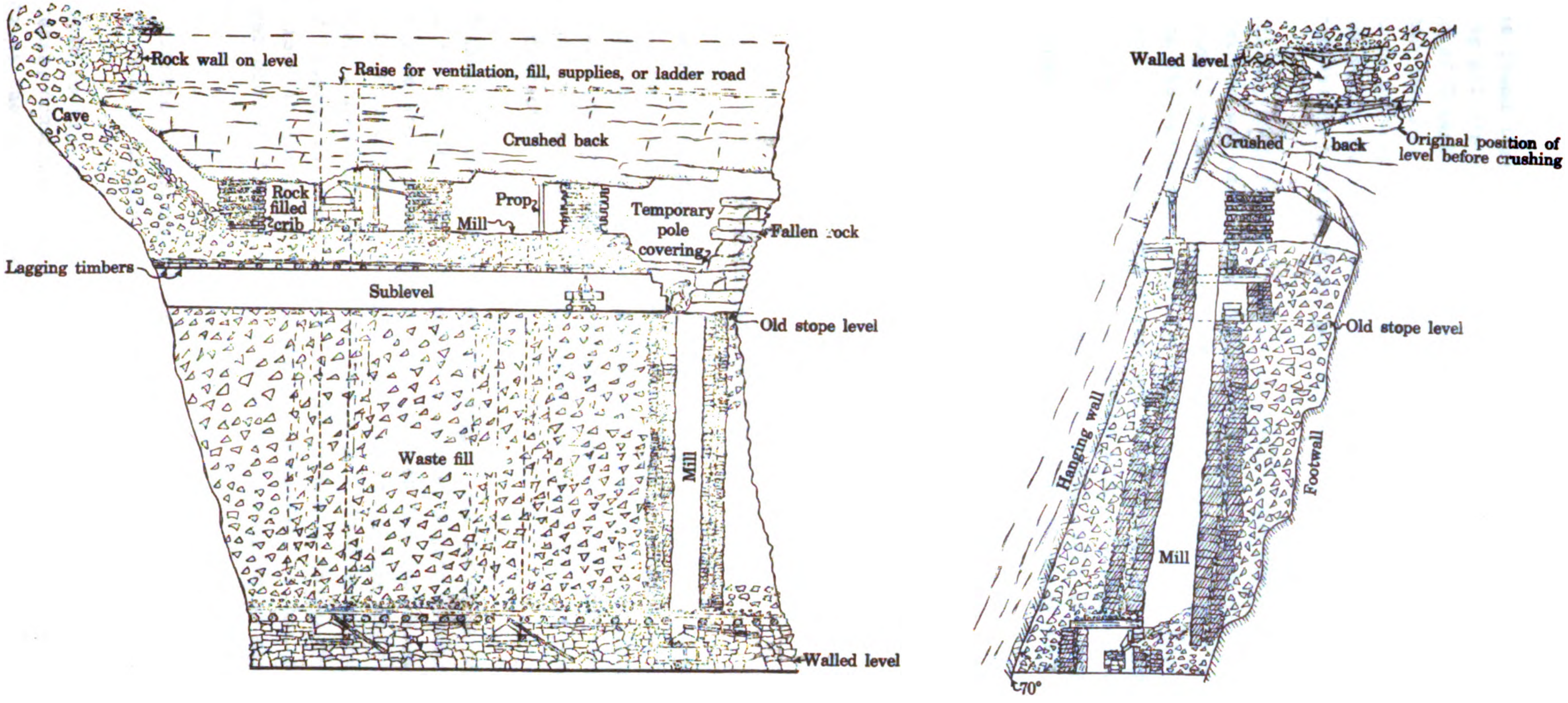


Figure 15.—Section through level, old mining method



LONGITUDINAL SECTION

CROSS SECTION

Figure 16.–Recovering crushed floor pillars

It was found that after 55 per cent of the ground in a given area had been mined out the remaining pillars would begin to crush. An attempt to delay this crushing was made at the No. 4 end of Champion mine by allowing the fill to remain packed in the stopes and by dumping fill into the inclined stopes through small raises. A thin floor pillar was left under each level to prevent the level from caving in. By not disturbing the fill the squeeze was delayed a few years, but eventually the ground in this part of the mine started to crush. The method of recovering crushed floor pillars is shown in Figure 16.

The filling used for this method of mining came from barren rock discarded by the pickers in the stopes and waste rock from development openings. The latter was hoisted in the shaft and dumped into a diagonal raise which connected with a raise paralleling the shaft, from which the waste rock could be tapped at each level. For many years, while mining was being done in the upper and richer portions of the lode, there was an insufficient amount of discard and waste rock from development work. To make up this deficiency in fill, stamp sand was brought back from the stamp mill, dumped into the waste raise, tapped off at the levels where needed, and distributed in the stopes by means of compressed air.

New Mining Method

The chief object of changing from mining on the advance to mining on the retreat was the desire to have the crushing occur in the abandoned worked-out areas instead of in those areas where mining is still taking place. Mining on retreat meant but one working place on a level. To increase production from a level it was necessary to adopt a sublevel method, which gives three stopes at the inside end of each level (fig. 17).

Hand Sorting and Selective Mining

There were certain features of the old Baltic mining method which so adequately met the physical conditions encountered in the Champion lode that it was highly desirable not only to retain them in any new method but, if possible, to arrange the stoping so that these features could be used more effectively. Hand-sorting of rock broken in the stopes, introduced in the Champion mine in 1905, solved the difficulty of profitably mining a copper deposit of this character.

The Champion lode is wide, and the copper may occur on the hanging side, on the foot side, or in the middle. It is common to encounter a good stretch of copper on the hanging side of the lode and a good stretch of copper on the foot side of the lode, separated from each other by 4 or 5 feet of barren rock. In some places the copper occurs only on the foot and in other places only on the hanging side. When drifting in the lode in copper ground it is not unusual for the character of the ground to change from good to poor and vice versa several times in the course of a month. Moreover, in the stretches of good copper ground the copper occurs, for the most part, in small nuggets or masses surrounded by areas of barren rock.

When drifting, sorting of the rock is accomplished simply by loading the cars either with poor rock or copper rock and disposing of them as such.

It would be highly undesirable when stoping to send to the surface as copper rock all the rock broken, containing, as it does, over 40 per cent of barren rock. A study of the cost data given at the end of this paper indicates clearly the economics of this problem.

Haulage and hoisting, exclusive of fixed maintenance charges, at present cost 25 cents per ton; preliminary crushing in the shaft house, 6 cents per ton; transportation to the stamp mill, 24 cents per ton; and stamping, 40 cents per ton. This indicates that there is a saving of 95 cents on every ton of barren rock that can be left in the stopes. Furthermore, eliminating barren rock from the rock shipped from the stopes increases its copper content per ton and all subsequent costs, figured on a per pound of copper basis, are decreased proportionately.

Difficulties due to barren rock in the lode are encountered in all mines in this district to a greater or smaller degree. Some of the narrower mines in the district have met the difficulty very successfully by mining around the larger areas of barren rock and leaving these areas as pillars to support the openings, using shrinkage stoping. In the Champion mine, where copper in the foot or hanging is often hidden from the miners by horses of barren rock, it is desirable to give the miners great freedom in the matter of breaking barren rock on either the foot or hanging side of their stopes. This practice has found tens of millions of pounds of copper in this mine. Because the amount of barren rock to be disposed of is increased by this practice and because of the physical conditions in the Champion lode, such as width of lode, dip, and a bad hanging, it was necessary to adopt a filling method. In addition to hand sorting, the sublevel method of mining now practiced, with sublevels separated by 25 feet of rock, permits mining around the larger areas of barren rock.

DEVELOPMENT

Main-level drifts are driven fairly straight and of standard size to the boundary. About 200 feet from the boundary a raise is driven to the level above. Stations are cut in this raise 33 feet and 67 feet from the floor of the main level. From these stations subdrifts are driven in both directions, using 15-hp. slusher engines and scraping directly into the raise. These subdrifts are driven the full width of the copper and explore thoroughly the foot and hanging sides of the lode. When the subdrifts reach the boundary raises are again put up to the level above, and stoping starts from the sublevels at the bottom of these raises. Inclined slices are carried up at an angle of 38°, so that when fill is introduced from above it takes its angle of repose.

STOPING

The subdrift at the bottom of a stope has been cut out to the full width of the copper-bearing part of the lode (see fig. 17). Loose ground is supported on props, with flat 6-inch head boards. The miner drills his round of holes parallel to the angle of repose of the fill, using four, five or six holes across the stope, depending on its width. The burden on these holes is 3 to 4 feet at collar and point. The holes are drilled to a depth of 10 feet. The round is blasted against the fill. The rock broken is picked or sorted, the copper rock thrown into a small car and trammed to the nearest raise, and the barren rock thrown to the foot and hanging of the stope. The miner advances his breast up the slope at an angle of 38° until a small 2 to 4 foot pillar is left, supporting the fill in the worked-out stope above. In wide stopes this small pillar must be left 4 feet thick. The pillar is drilled over, and the holes are left to stand without blasting until all copper rock has been picked out of the stope and all exploration has been done on the foot and hanging sides. The foot sides of some stopes have been mined to widths of over 60 feet before the last pillar was blasted out. When all such work has been completed in a stope the pillar is blasted, and the fill from above rushes down and completely fills the stope. Most of the copper rock contained in the small pillar last blasted is found at the bottom of the pile of fill. The miner now starts again at the bottom of the slope and goes up with another inclined slice.

The thickness of the burden put on the holes varies; in very lean rock, where a considerable discard is made, a small burden is used to facilitate the work of hand sorting.

Experiments are being made to determine the advisability of using slushers instead of stope cars to transport to the raise the copper rock that has been thrown to the bottom of the stope.

DEEP MINING PROBLEMS

Mining Method

In changing the method of mining consideration was given to those problems that will arise with greater depth. The Champion mine was worked by the Baltic mining method with notable success, and it was only when the difficulties encountered due to crushing ground involved unusual maintenance expenditures that the method of attack was altered. The advancing system of mining was used up to depths of approximately 3,000 feet vertically and about the same depth on the dip. The depth to which the retreating system can be used can be estimated by a study of the Calumet & Hecla Conglomerate mine, where mining is being profitably done on retreat at a vertical depth of over a mile.

At the Champion mine no pillars whatsoever are left, either temporarily or permanently, for purposes of support. About 45 per cent of the area between the longitudinal boundaries of the mine is left as unminable ore. These areas of unminable ore are not made up of small pillars but rather take the form of blocks of large dimensions occurring between the chutes of profitable ground. For example, in one place in the mine, under No. 2 shaft (which has been abandoned), a block 1,500 feet by 1,000 feet after extensive exploration proved to be unminable. In the present workings numerous smaller patches of apparently barren rock are being left as pillars.

Although all the shafts were started in the lode, Nos. 3 and 4 shafts are now about 60 feet in the foot of the lode on account of the flattening which takes place at depth. It is planned to maintain the shafts at least this distance in the foot, and at present there appears to be no reason why the lode can not be mined out over the shaft where the shaft is such a distance in the foot. At No. 1 shaft, from the seventh to the fifteenth levels, the lode was as little as 35 feet to the foot of the shaft and was mined out completely over these eight levels without leaving any shaft pillars. This practice, so far from affecting the shaft unfavorably, rather indicates that all pressure was relieved from the shaft in this area. It seems important not to do such mining, either above or under the shaft, unless there is at least 60 feet of ground between the shaft and the workings.

The question of whether, with funds available for extensive development, it would be advisable to apply the retreating system on the lowest level, first extending stoping from the lowest level upward as well as laterally toward the shaft, can not be applied to this mine, since limits of depth are unknown. It does not seem that such a practice would be advisable in a method such as that adopted by the Champion mine, where filling is used. Our present method of spreading fill in the stopes is by the use of gravity, and mining from the bottom of the property upward would involve a greater amount of handling of fill. The filling material is supplied by pulling fill from the upper stopes and by broken hanging wall rock.

Although it might seem that the overlying rock pressures would aid in mining the ore, as a matter of fact crushing of the ground creates such a hazard that any benefit from such pressures is more than offset.

The level interval - only 100 feet - would seem to involve an excessive cost of development, maintenance, and equipment, and it is possible that as the mine becomes more extensively developed for mining on retreat this interval could be increased. However, to provide sufficient working places as well as to explore the lode throughly before production starts, it is necessary at present to drive levels not more than 100 feet apart.

Support

Where the shaft was sunk in the lode 100-foot pillars were left on either side. At present No. 1 shaft is over 60 feet to the hanging of the lode and Nos. 3 and 4 shafts over 60 feet to the foot of the lode, and no shaft pillars are left. It appears that had the shafts continued in the lode it would have been necessary to increase the size of the shaft pillars left for support.

Temporary support in the stopes is provided by the filling material; heavy ground in the stopes is caught up on props or cribs until the stope can be filled.

In order that stoping on one sublevel may not interfere with the stoping on the sublevel immediately above the stope above must precede the stope below by about 40 feet. This gives a diagonal line of stope faces, and there seems to be no particular disadvantage in this practice.

The principal lines of weakness in the surrounding rock structure have been determined by experience and recently by a very thorough survey made by Dr. W. R. Crane. These lines of weakness have very definitely affected every operation in our mining method.

Although there seems to be little question but that the support given the hanging wall by the stope filling does not stop the squeeze, it limits the amount of disintegration and caving that can take place in the hanging country. As soon as the fill has been compressed, due to the caving of the hanging, it acts as a support and allows mining to proceed in the stopes before the full weight of the hanging country reaches them. Because of the mineral seams and slips in the hanging wall caving of the hanging trap commences very soon after the lode has been mined.

The sublevel method now employed allows rapid mining of a given block of ground, and rapid stoping is a decided advantage in avoiding the development of rock pressure and crushing.

The small pillars of barren rock left in the stoping operations seem to crush later without causing any disturbance in the working faces. The barren blocks of large dimensions, some of which cover many thousand square yards in area, carry the weight of the hanging country for a considerable time, and when one of these crushes there follow what is commonly known as an "air-blast" and extensive shaking up of the ground in its neighborhood.

Hoisting and Pumping

There is very little water in the lower levels of the Champion mine, and the problem of pumping at depth is not yet serious.

It appears that with depth and the possibility of crushing reaching the shaft, causing uneveness in the road bed and delays for repairs, hoisting speeds will be reduced rather than increased and greater emphasis placed on sorting and selection of rock before it is hoisted.

UNDERGROUND HAULAGE

On the upper levels of the mine the track gage is 24 inches. Two-and-one-half-ton cars are used for tramming copper rock to the shaft and for hauling filling material from the waste raise. The chutes used in the older parts of the mine are shown in Figure 15.

The copper rock is dumped into the skip by dumpers, two cars to a skip, by means of a turntable and cradle. Waste rock for filling is dumped down into the raises between the rails, the cars being up-ended by 10-inch air lifts.

The mine is equipped with seventeen 4-ton, 15-hp. General Electric locomotives, twenty-four 4-ton, 30-hp. Goodman locomotives, and one Jeffrey locomotive. In the lower levels the track gage is 36 inches.

The track, trolley, and all haulage equipment are put in and maintained according to printed standards. Strict attention is given on all levels and in all stopes to "good housekeeping."

The 5-ton cars used on the lower levels and the arrangements for dumping them are shown in Figure 7. The timbered chutes at the bottoms of the raises are shown in Figure 14.

PERCENTAGE OF EXTRACTION

Of the rock broken in the mine for all operations in 1930, 56 per cent was sent to surface as stamp rock; the balance was left in the mine as stope filling. At present very little waste rock is dumped on surface, but the amount is increasing.

WAGE CONTRACT AND BONUS SYSTEM

With the exception of repair and maintenance gangs all men in the mine work on contract. About 71 per cent of the men on the underground payroll make money on their contracts; the average pay per contractor is about 50 cents per shift above the "company-account" base.

Shaft Sinking

Shaft sinking is paid for at a set price per foot sunk and covers mining, mucking, and timbering labor. Up to a limited number of pounds per foot sunk powder is free; all powder used above that limit is paid for at cost by the contractors.

Drifting (Main-Level and Sub Drifts

Drifting is paid for at a set price per foot of advance, the price varying for each different width of drift and covering labor of mining, mucking and disposing of rock. Up to a limited number of pounds per foot of advance powder is free, the amount allowed varying with each different width of drift; any excess powder is paid for at cost by the contractors.

Stoping

Because hand sorting is practiced in the mine the stoping contracts are somewhat more complicated than the development contracts. Barren rock must be kept out of the copper cars, and copper rock must not be discarded as waste. The rule given to pickers is simple: Large pieces of rock containing any copper whatsoever that can be seen must be shipped as copper rock; fine rock must be shipped as copper rock unless ordered left in the stope by the boss. Cars of copper rock are inspected by the bosses and by a poor-rock inspector. Discard in the stopes is inspected by the bosses and the captain.

In the stopes the contract system is balanced in such a way that the best pay will be made by those contractors who carefully sort their rock. The organization in a stope consists of a miner and one or two pickers on each shift. The miners' company-account rate is 45 cents a day above the pickers' company-account rate. These men mine, pick, and do all the propping necessary in their stope. Each participates in the bonus earned for the month in proportion to the number of shifts he has worked. Engineers measure monthly the volume of the excavation made in each stope to determine the total rock broken in each stope and the average width of the stope. Underground records show the number of cars of copper rock shipped from each stope. The time books show the number of shifts of all labor working in each stope. From these data the engineers calculate monthly the bonus to be paid to each party of contractors.

The use of three tabulated rate schedules facilitates the work of calculation. The rate schedules cover:

1. The bonus per shift to be paid for a given tonnage of rock broken in a stope of a given width; the wider the stope, the greater the tonnage broken per man per shift for a given bonus.

2. The bonus per shift for a given tonnage of copper rock produced, after sorting, from a stope showing a given ratio of total broken to total copper rock produced; the greater the amount of barren rock that must be handled in sorting, the greater the bonus pay per shift for a given tonnage of copper rock produced.

3. The allowance of powder per ton of rock broken for each width of stope.

VENTILATION

The subject of ventilation in the Champion mine has recently been thoroughly covered by a United States Bureau of Mines information circular now in preparation, Natural Ventilation in the Michigan Copper Mines, by G. E. McElroy.

The Champion mine is comparatively shallow. So far good ventilation has been maintained in all working places; even the blasting may be done at any time during the working shift. Analyses of the air in what were considered the worst stopes and drifts showed no carbon monoxide and only a very slight deficiency in oxygen.

FIRE HAZARDS

The greatest fire hazards in the mine are faulty electrical installations and open lights. Smoking underground is strictly prohibited.

A well-equipped mine rescue-station is maintained, containing six McCaa 2-hour oxygen apparatus and several all-service gas masks. Twenty-four picked men have received United States Bureau of Mines certificates in mine rescue-training and are given additional training each month by the safety inspector. Warning to the men in the mine in case of fire has been provided for by making suitable connections in the air main for the introduction of stench. In the mine, water barrels and buckets, plainly marked "FIRE", are placed on each plat, directly opposite the main hoisting compartment. These barrels are maintained in perfect condition and serve, not only as a protection in case of fire, but also as a constant reminder to the men. Forty-three 1½-quart, Pyrene extinguishers and six Foamine, 2½-gallon extinguishers are placed at hazardous points in the mine. In Nos. 1 and 4 shafts, water lines with suitable fire-hose connections are run from the surface to the bottom of the mine. Small tanks with overflow connections are placed on every third level to break the pressure in these water lines. Bulkheads and doors have been constructed to cut off certain sections of the mine in case of fire.

SAFETY METHODS AND FIRST AID ORGANIZATION AND TRAINING

Accident-prevention work at the Champion mine is regarded as a major operation by the president and all company officials. The safety organization consists of a general safety committee, of which all department heads are members, having direct charge of accident prevention work. In addition, the mine employs a full-time safety inspector.

The results of the aggressive safety campaign which was started in 1927 are indicated in the following table, giving the accident record since 1926:

Year	Total of all lost-time accidents
1926	430
1927	339
1928	254
1929	172
1930	92
1931 (3 months)	11

The accident-prevention work takes the form of repeated inspections, investigations of all accidents and near accidents, mimeographed safety news letters every two weeks to all foremen, well-conducted bulletin-board service, rigid enforcement of safety rules, and periodical examinations of the men to determine their understanding of the safety rules, regular safety meetings for foremen, and individual awards to foremen and men who maintain good no-accident records. Hard-toed shoes, hard hats, and goggles must be worn by all men in the mine. Gloves must be worn by men doing certain kinds of work.

All the men in the mine have received certificates of training in first aid from the United States Bureau of Mines. This training was done in 1930, and since then all new men who have been employed have been trained and received certificates. For the purpose of reviewing first-aid training classes are held periodically, and all men are requested to attend. All first-aid training is taken on the men's own time. The same training was given to all men employed in the surface plants. First-aid boxes containing the necessary bandages, etc., are stationed on every level underground and at suitable places on the surface.

Table 1.- Summary of Costs at Champion Mine

Period: Five months—August 1, 1930, to December 31, 1930.

Ore hoisted during period:——193,597 tons.

Mining method: Inclined cut-and-fill, partly from sublevels, retreating.

Underground Costs Per Ton of Ore Hoisted

	Labor	Supervision	Compressed air, drills, and steel	Power cost	Explosives	Timber	Other supplies	Total
Development	$0.297	$0.023	$0.069		$0.069	$0.031		$0.490
Mining (stoping)	.794	.056	.128		.103	.061	$0.020	1.163
Transportation underground & hoisting	.390	.027		$0.089		.017	.029	.552
General underground expense	.045			.008			.021	.078
Mine unwatering	.027	.001		.095			.010	.133
Surface expense directly applicable to underground operations	.091						.021	.112
Total	1.644	.107	.197	.192	.172	.109	.101	2.528
Cost per pound of copper	.036	.002	.004	.004	.003	.002	.002	.055

Note:- About 40 per cent of rock broken is sorted out underground as waste.

Table 2.- Summary of Costs in Units of Labor, Power, and Supplies

Champion mine August 1, 1930, to December 31, 1930.

Tons of copper rock hoisted: 193,597 tons of 46 pounds copper each.

Mining method: Inclined cut and fill, partly from sublevels, on retreat.

A.-Labor (man-hours per ton)		Development	Mining	Total
Breaking (drill and blast)		0.18	0.55	0.73
Timbering and filling		.09	.21	.30
Shovelling and hand sorting, underground		.18	.73	.92
Haulage and hoisting		.04	.82	.86
Supervision		.03	.09	.12
General		.02	.10	.11
Total labor underground		.54	2.50	3.04
Average tons per man per shift		14.6	3.17	2.64
Labor —— per cent of total cost		62	67½	66
Average tons per man per shift on surface charged underground				65
B.-Power and supplies, per ton				
Explosives, per ton of ore	lbs.	.5	.8	1.3
Timber (board measure), per ton of ore	ft.	1.2	3.1	4.3
Total power	kw.h.per ton			21.7
Air compression		4.0	8.4	12.4
Hoisting		.7	3.3	4.0
Pumping				4.7
Ventilation, lighting, etc.				1.0
Other supplies —— per cent of total supplies and power				48.5
Supplies and power —— per cent of total cost				17.8
C.-Percentage of total cost				83.8

Table 3.- Detail of Costs in Units of Labor, Power, and Supplies

	Sinking	Drifting	Crosscuts	Raising	Total all development
Size of excavation.......... feet	10 by 23	8 by 13½	-	4 by 8	-
Timbered or not..........	Timbered	Part	-	Timbered	-
Physical properties of rock..........	Hard, loose	Hard, firm	Hard, firm	Hard, firm	
A.-Labor--Man-hours per ft.					
Breaking (drilling and blasting)..........	14.7	4.9	-	6.6	5.8
Timbering..........	36.3	1.2	-	-	2.8
Shovelling..........	23.1	6.2	-	-	5.9
Haulage and hoisting..........	16.0	.8	-	-	1.4
Supervision..........	1.1	1.1	-	1.1	1.1
Total labor..........	91.2	14.2	-	7.7	17.0
Feet per 8-hour shift..........	.088	.56	-	1.0	.47
B.-Power & Supplies (per ft.)					
Explosives..........lbs. per ft.	25	17.0	-	14.	17
Timber, (b.m.) per ft.......... ft.	330	11	-	8	28
Total power..........kw.h.per ft.					
Air compression..........	-	-	-	-	130
Hoisting..........	-	-	-	-	27
Haulage and ventilation..........	-	-	-	-	4.5
Other supplies..........					
Labor — per cent of total cost..........	-	-	-	-	60.5
Power and supplies — per cent of total cost..........	-	-	-	-	39.5

Table 2.- Summary of Costs in Units of Labor, Power, and Supplies

Champion mine August 1, 1930, to December 31, 1930.

Tons of copper rock hoisted: 193,597 tons of 46 pounds copper each.

Mining method: Inclined cut and fill, partly from sublevels, on retreat.

A.-Labor (man-hours per ton)	Development	Mining	Total
Breaking (drill and blast)	0.18	0.55	0.73
Timbering and filling	.09	.21	.30
Shovelling and hand sorting, underground	.18	.73	.92
Haulage and hoisting	.04	.82	.86
Supervision	.03	.09	.12
General	.02	.10	.11
Total labor underground	.54	2.50	3.04
Average tons per man per shift	14.6	3.17	2.64
Labor — per cent of total cost	62	67½	66
Average tons per man per shift on surface charged underground			65
B.-Power and supplies, per ton			
Explosives, per ton of ore lbs.	.5	.8	1.3
Timber (board measure), per ton of ore ft.	1.2	3.1	4.3
Total power kw.h.per ton			21.7
Air compression	4.0	8.4	12.4
Hoisting	.7	3.3	4.0
Pumping			4.7
Ventilation, lighting, etc.			1.0
Other supplies — per cent of total supplies and power			48.5
Supplies and power — per cent of total cost			17.8
C.-Percentage of total cost			83.8

Table 3.- Detail of Costs in Units of Labor, Power, and Supplies

	Sinking	Drifting	Crossouts	Raising	Total all development
Size of excavation........................ feet	10 by 23	8 by 13½	-	4 by 8	-
Timbered or not..	Timbered	Part	-	Timbered	-
Physical properties of rock............................	Hard, loose	Hard, firm	Hard, firm	Hard, firm	
A.-Labor—Man-hours per ft.					
Breaking (drilling and blasting)....................	14.7	4.9	-	6.6	5.8
Timbering..	36.3	1.2	-	-	2.8
Shovelling..	23.1	6.2	-	-	5.9
Haulage and hoisting..	16.0	.8	-	-	1.4
Supervision..	1.1	1.1	-	1.1	1.1
Total labor..	91.2	14.2	-	7.7	17.0
Feet per 8-hour shift...	.088	.56	-	1.0	.47
B.-Power & Supplies (per ft.)					
Explosives.......................................lbs. per ft.	25	17.0	-	14.	17
Timber, (b.m.) per ft................ ft.	330	11	-	8	28
Total power......................................kw.h.per ft.					
Air compression..	-	-	-	-	130
Hoisting..	-	-	-	-	27
Haulage and ventilation..............................	-	-	-	-	4.5
Other supplies..					
Labor —— per cent of total cost..................	-	-	-	-	60.5
Power and supplies —— per cent of total cost..	-	-	-	-	39.5

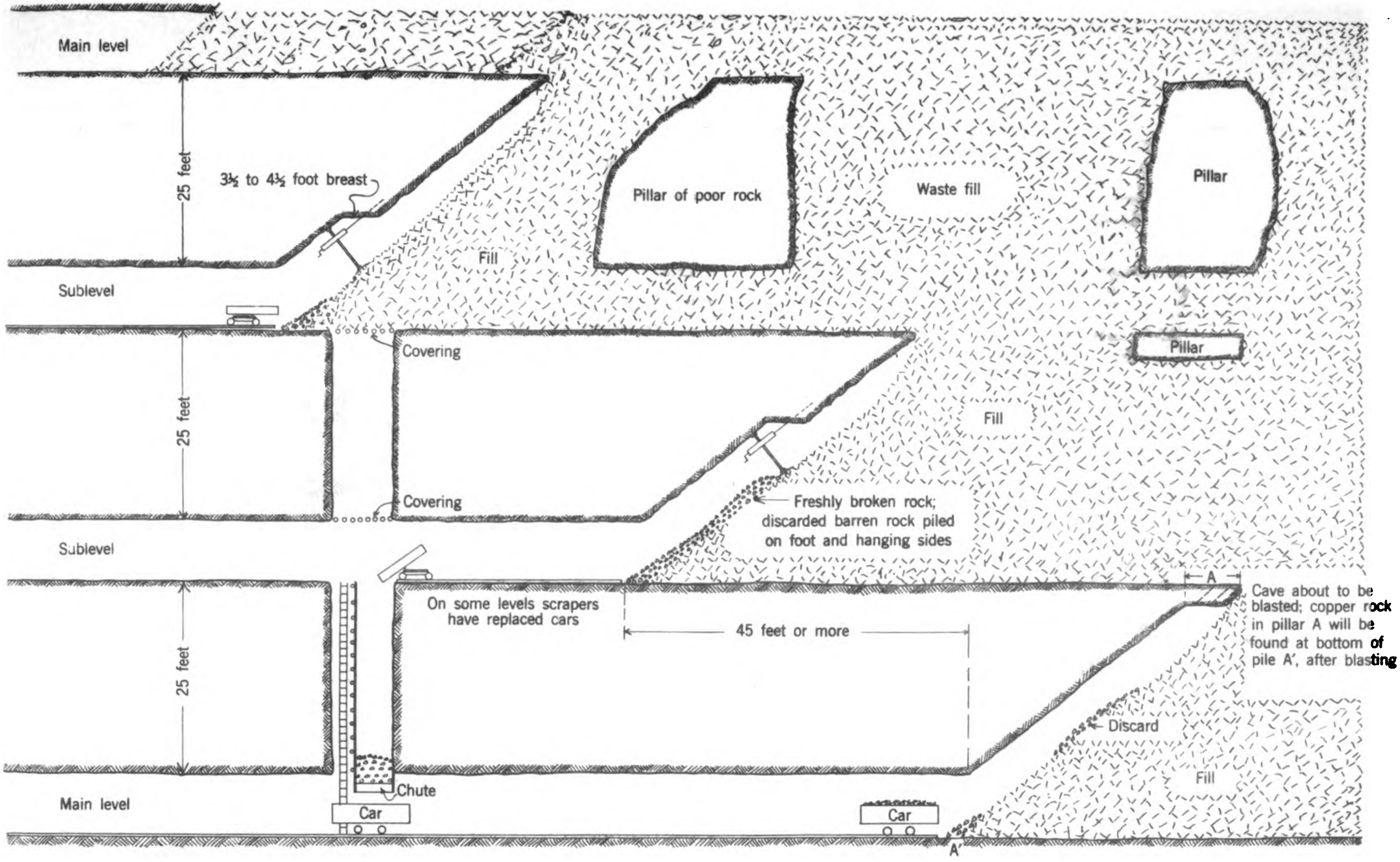

Main level
25 feet
3½ to 4½ foot breast
Pillar of poor rock
Waste fill
Pillar
Fill
Sublevel
Covering
Pillar
Fill
25 feet
Covering
Freshly broken rock; discarded barren rock piled on foot and hanging sides
Sublevel
A
Cave about to be blasted; copper rock in pillar A will be found at bottom of pile A', after blasting
On some levels scrapers have replaced cars
45 feet or more
25 feet
Discard
Fill
Chute
Main level
Car
Car
A'

Figure 17.—New stoping method—sublevel, inclined cut-and-fill